Chapter 2
Foundations of the Smart Identifier Network

In this chapter, we introduce the foundations of the SINET in order to allow the audience to understand the background and philosophy of the SINET. The two-layer-based primary reference model, three resolution mapping models and seven main operations are outlined as an overview of the SINET. The basic principles and workflow of the SINET architecture are the main topics of this chapter, through which the superiority of the SINET over the traditional Internet is indicated. Based on this chapter, the detailed principles of the SINET will be further given in Chaps. 3 and 4.

2.1 Problem Statement

The current Internet architecture was designed over 40 years ago only for some primitive purposes of data communications. Due to the limitations of technology at that time, the original design of the Internet did not consider many advanced requirements and functions. However, along with the massive emergence of new applications, the current internet is facing many unprecedented challenges, such as poor security, low mobility and high energy consumption. How to resolve these problems *comprehensively* and *effectively* in order to allow the Internet to meet the emerging demands of this community is a well-known major challenge.

We explore the root causes of the problems of the current Internet and conclude that it is what we call *triple bindings* that result in most of the existing Internet issues. These *triple bindings* make the Internet relatively *STATIC* and *RIGID*, which greatly restricts the development of the traditional Internet. The *triple bindings* refer to the resource/location binding (*r/l binding*), the user/network binding (*u/n binding*) and the control/data binding (*c/d binding*), respectively. Figure 2.1 illustrates the cause and effect related to the *triple bindings* and some of the problems in the current Internet.

H. Zhang et al., *Smart Collaborative Identifier Network*,
DOI 10.1007/978-3-662-49143-0_2

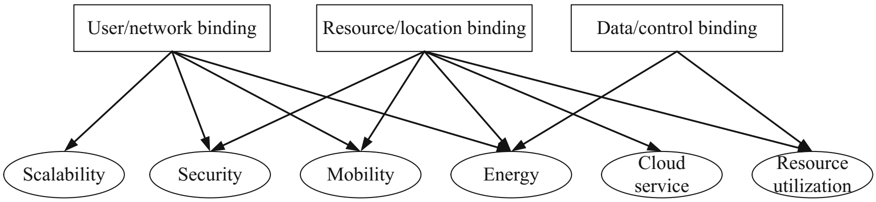

Fig. 2.1 The triple-binding and cased problems

Lately, many clean-slate Internet designs have been proposed to loosen or decouple the aforementioned bindings. However, most of the existing future Internet proposals only partially decouple the *triple bindings*. For example, CCN [1] and NDN [2] aim to decouple the service resources from their locations by using content-based addressing and in-path caching; LISP [3] and MobilityFirst [4] decouple user information from an access network by separating routing locators and user identifiers; SDN/OpenFlow [5] separates flow control from data transfer by using two different planes: the control plane and data plane.

It is worth noting that the three bindings are not entirely independent of each other. For example, mobility support issues are related to both the *u/n binding* and the *c/d binding*. And security problems may be affected by both the *r/l binding* and the *u/n binding*. Therefore, a *holistic approach* is needed to resolve the *triple binding*-related issues completely. The SINET is a collaborative future Internet architecture, which aims to provide an overall clean-slate design of the future Internet enabling the decoupling of the *triple bindings* completely.

Before introducing the Smart Identifier Network (SINET), we first mention the Identifier-based Universal Network (IUN) architecture, which is a foundation of the SINET. The IUN was proposed as the main achievement of the national 973 Program "Fundamental Research on the Universal Network for Supporting Pervasive Services" of the *NGIT*. Based on the IUN, the SINET was further supported with the fund of the second 973 Program "Fundamental Research on Smart Collaborative Network."

To help the readers better understand the design principles of the SINET, we define some of its basic technical terms. These technical terms will be consistently used in the following chapters.

The *COre Network (CON)* is in charge of transmitting the backbone data flow. The CON is usually operated and managed by the Internet Service Provider (ISP). In general, the CON can be divided into numerous different management domains. There are relatively small variations between these management domains. Additionally, an ISP can operate and manage multiple such management domains.

The *ACcess Network (ACN)* is a network between the CON edge interface and the user terminal equipment. The ACN may contain a single node or a fixed/mobile subnet (such as a campus network and an enterprise network). The user terminal equipment in the ACN is usually a source or destination node that generates the network data traffic.

The *Access IDentifier (AID)* is a unique identifier that denotes the identity of the terminal accessed to the network. When a terminal is connected to a network, it has at least one AID. Besides, the AID of the terminal will remain unchanged even if its location changes.

The *Routing IDentifier (RID)* is an identifier used for the working CON equipment. It is used for interconnecting different CON equipment and is used for the packet locating, addressing and forwarding in the CON.

The *Service IDentifier (SID)* is an abstract description of service resource information, which is used to uniquely represent a service resource datum (such as a video, a web page or a picture) or a service type (such as telephone or mail). In the SINET, the SID has a flat structure and does not change with the time and location of service providers.

The *Connection IDentifier (CID)* identifies the process of a user obtaining a service. Since the required service may be the combination of different services, such as a web containing multiple media, one CID may correspond to multiple network sources or destination nodes.

Resolution Mapping (RM) is used to generate the corresponding relationship between different identifiers, i.e., AID, RID, CID and SID. In detail, the SINET contains three kinds of RMs.

The *Access Switching Router (ASR)* is located at the edge of an ACN. It is responsible for the access of various fixed/mobile terminals and ad-hoc networks. Besides, the ASR is responsible for the authentication of terminal users and the mapping between AID and RID in the ACN as well as managing the user data forwarding in the CON.

The *General Switching Router (GSR)* is the backbone routing equipment in the CON, which is responsible for the unified routing and forwarding in the CON.

The *IDentifier Mapping Server (IDMS)* is used to manage and store the mapping rules and algorithms of the SINET. It is also responsible for disseminating the mapping rules and mapping processes to ASRs to achieve the resolution mappings.

The *Authentication Center (AC)* is used to perform the bidirectional authentication process when a node accesses the network. If the node passes the authentication, the packets from the nodes can be routed in the network. Otherwise, the packets will be discarded.

In the following chapters, we will elaborate how the SINET decouples the *triple bindings* of the current Internet and promotes a smart and collaborative Internet in both theory and practical applications.

2.2 Primary Reference Model

Over the past decades, the Internet and telecommunication networks both have obtained huge success, providing researchers with many useful and valuable suggestions. The research on the future Internet should absorb the advantages of the Internet as well as the telecommunication network [6, 7]. Before introducing the

SINET model, it is necessary to analyze and compare the essence of these two network architectures.

A traditional telecommunications network can be seen as a collection of terminal nodes, links and any intermediate nodes that are connected to maintain communications. The original telecommunication network was designed for *voice transmission*. This network architecture is composed of three parts, including the carrying network, service network and supporting network. The carrying network and supporting network constitute the network infrastructure and provide the basic network platform for services. The service network is usually used to provide a specific business, such as selecting a service, building connections and services.

Different from the traditional telecommunication network, the Internet was initially designed for *data transmission*. It is composed of a series of user access equipment, network switching/routing equipment and specific service servers. These network devices are connected through different media and together constitute the foundation of Internet communication. When users need to obtain the data through the Internet, the program of user terminals will first build connections with the corresponding servers. Then, the required data will be transmitted through the built end-to-end connections, such as the TCP and UDP connections. Finally, the data will be forwarded and routed according to the IP address of the corresponding data packet.

Based on the above analysis, we recognize that the above network architectures share several common features. The first one is that network equipment is interconnected to form a *network infrastructure*, in which all nodes are able to cooperate with each other through the corresponding mechanisms. The second is that the service requester and service provider are connected because of the service provision. They first build connection channels based on the network infrastructure before the data transmission. Then, the channel will be released after the termination of the service provision. Therefore, based on the above two features, we originally created the novel SINET architecture, which contains only two layers, the *Network Component Layer* and *Pervasive Service Layer*, by comparison with the *OSI reference model* [8] and *TCP/IP reference model* [9].

The Network Component Layer is in charge of accessing of all kinds of network terminals, routing/forwarding of data packets and providing a unified communication platform for network services such as data, voice and video. It corresponds to the *Physical Layer*, the *Data Link Layer* and the *Network Layer* in the traditional OSI reference model or the *Network Layer* and the *Network Layer* in the TCP/IP reference model. The Pervasive Service Layer is in charge of managing the service data resource and the unified control of network connections. It corresponds to the *Transport Layer*, the *Session Layer*, the *Presentation Layer* and the *Application Layer* in the traditional OSI reference model or the *Transport Layer* and the *Application Layer* in the TCP/IP reference model. The comparison and relationship of these three network architectures are shown in Fig. 2.2.

This two layer-based reference model absorbs the characteristic of the existing network architectures but removes their disadvantages. It simplifies the design of the network and improves the flexibility of the network design. Based on this

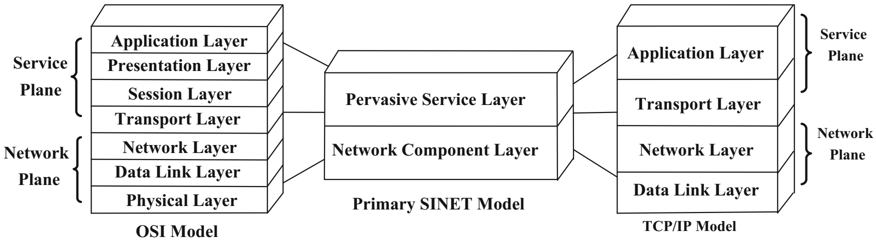

Fig. 2.2 The comparison of three network architectures

model, more detailed principles are derived from the current clean-slate future Internet designs [10–17] and are considered to overcome numerous drawbacks of the current Internet. Here, *eight main requirements* for the future Internet are listed as follows:

Information-/Data-Centric. While the current Internet was designed centering on hosts, its current major usage is data retrieval. Accordingly, there is an increasing consensus that the future Internet should be information-/data-centric. That is, content should be assigned the first priority and be processed independently.

Efficient Support for Mobility. With the rapid increase in the number of mobile devices, the future Internet architecture should efficiently support mobility.

Enhanced Security. The current Internet employs a default-on model and any host is able to send packets to a remote host, which makes the current Internet vulnerable to cyber attacks. Therefore, the future Internet should offer receivers the ability to control incoming traffic, especially to refuse unwanted traffic.

Enhanced Scalability. The future Internet should provide better routing scalability than the current Internet. The routing table size should be significantly less than that in the current Internet.

Efficient Support for Multi-homing. In multi-homing, a host (or network) is simultaneously attached to multiple networks. While the current Internet is cumbersome when supporting multi-homing since it causes serious routing scalability issues, the future Internet architecture is expected to support multi-homing efficiently.

Ease of Traffic Matrix Estimation. It is difficult to estimate traffic matrices in the current Internet. However, since traffic matrices are critical inputs to many aspects of network management such as traffic engineering and network provisioning, the future Internet should make it easy to precisely estimate traffic matrices in real time.

Deployability. Although we aim at a clean-slate design, the future Internet architecture should be deployed without incurring significant cost.

Encouraging Innovation. The future Internet architecture should allow each network to use its preferred network architecture and routing mechanism so that different network technologies can be simultaneously deployed and contested, thus encouraging innovation.

In the SINET, the Network Component Layer brings in the *Virtual Access Module (VAM)* and the *Virtual Backbone Module (VBM)*. The Pervasive Service Layer introduces the *Virtual Service Module (VSM)* and the *Virtual Connection Module (VCM)*. Meanwhile, four kinds of identifiers are introduced, i.e., the Service IDentifier (SID), Connection IDentifier (CID), Access IDentifier (AID) and Routing IDentifier (RID). To better cover the mentioned requirements, we establish the interaction between the two layers to connect four different function modules as shown in Fig. 2.3.

All the above modules are responsible for different network functions and building the basic functional units of the network communication.

The *VAM* carries out the AID-related functions, which are responsible for completing unified access of all kinds of network terminals such as the fixed networks, mobile networks and sensor networks. It is also responsible for providing data switching and forwarding in the ACN.

The *VBM* carries out the RID-related functions, which are responsible for switching, routing and forwarding of data packets, as well as maintaining the interconnection of network equipment.

The *VSM* carries out the SID-related mechanisms, which are responsible for the unified description, management of all kinds of network service resources and provision of a unified service interface for user application programs.

The *VCM* carries out the CID-related mechanisms, which are responsible for generating virtual access channels for specific network services according to the service demand and real-time network status. Meanwhile, it also determines the corresponding network service interface for data received from different connection channels.

Besides building the modules, how to organize them together to complete the communication efficiently and collaboratively is very important. The current

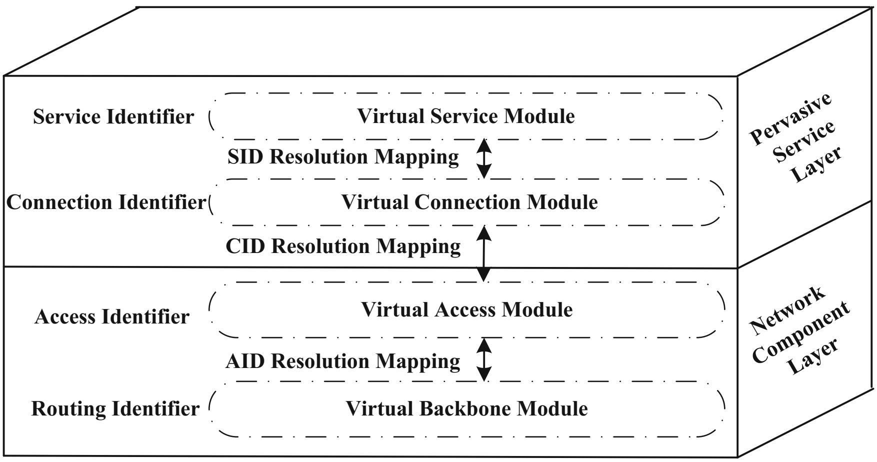

Fig. 2.3 Foundational reference model of the SINET

Internet adopts the logic interfaces to realize the connection between the upper-layer protocol entity and lower-layer protocol entity. Usually, this interface design is specific for a certain function and lack of flexibility. What is more, there is no unified description for the interactive information among different layers. With the rapid increase of the number of network services and the network facility complexity, this simple design cannot meet the requirements of the future Internet. In SINET [18–20], three kinds of resolution mappings are introduced to select the appropriate network routings to meet the requirements of providing different network services. The next section will illustrate the resolution mappings in detail.

2.3 Resolution Mappings

In the primary SINET reference model, the three different resolution mappings comprise AID Resolution Mapping (AID-RM), SID Resolution Mapping (SID-RM) and CID Resolution Mapping (CID-RM).

2.3.1 AID Resolution Mapping

AID-RM is used to generate the corresponding relationship among accessing (in ACN), switching and routing (in CON). This mapping is able to insulate the ACN from the CON and to protect the privacy information of the user terminal, including its identity and location.

Suppose the AID space set is $X = \left\{x_i^{(j)} | i, j \in N\right\}$, where N is the natural number set, i represents a node, and j represents the jth AID of the node i. In the SINET, suppose that the number of access positions is Q and $X_q (X_q \subseteq X, 1 \leq q \leq Q)$ is the set of all AIDs in access position q. Similarly, suppose the RID space set is $Z = \{r_i | i \in N\}$ and $Z_q \subseteq Z$ represents the RID set used in access position q. Then, the *AID-RM* can be expressed as follows.

$$\begin{bmatrix} Z_1(t) \\ \vdots \\ Z_q(t) \\ \vdots \\ Z_Q(t) \end{bmatrix} \triangleq \Omega \begin{bmatrix} X_1(t) \\ \vdots \\ Z_q(t) \\ \vdots \\ Z_Q(t) \end{bmatrix}, \tag{2.1}$$

Here, $\Omega(\cdot)$ is the *AID-RM* function, which is used for completing the mapping transformation from the AID space to the RID space. Its inverse mapping $\Omega^{-1}(\cdot)$ will complete the mapping transformation from the RID space to AID space.

Additionally, Eq. 2.1 shows that Z_q and X_q are the functions of time t. The AID set X_q of all access nodes at the access location q will vary with the change of time t. After mapping $\Omega(\cdot)$, all the Z_q at access location q will also vary with the time t in the SINET.

AID-RM is an efficient design to separate the location information and identity information, and it can also solve the problems in the traditional network such as the routing scalability and node mobility. Besides, the design of the *AID-RM* successfully separates the access space and routing space. In the realization process of Eq. 2.1, we introduce the authentication mechanism to stringently check the mapping process. Consequently, the security of the CON is improved.

2.3.2 SID Resolution Mapping

SID-RM is used to generate the corresponding relationship between the network services and network connections to map the SIDs to CIDs.

In the SINET, the SID includes a set of kinds of service properties, such as $p_1, p_2, \ldots p_J$. For a service S, the SID is denoted as:

$$S \triangleq \phi\left[p_1^{(S)}, p_2^{(S)}, \ldots, p_J^{(S)}\right], \tag{2.2}$$

where $\phi(\cdot)$ denotes the SID generation operator; $p_j^{(s)} (1 \le j \le J)$ denotes the jth property of service S.

Suppose $S = \{s_i | i \in N\}$ is the SID space set, where N is the natural number set and i represents a node. We denote that the network service with a SID of $s_n(s_n \in S)$ is being obtained by node i as $s_i^n\left(s_i^n \in S\right)$. At the time t, all the services that node i is obtaining can be expressed as:

$$S_i(t) = \sum_n s_i^n d_i^n(t), \tag{2.3}$$

where $d_i^n(t)$ denotes whether node i is obtaining the network service $s_n(s_n \in S)$ at the time of t. The value of $d_i^n(t)$ is defined as:

$$d_i^n(t) = \begin{cases} 1, & \text{obtaining} \\ 0, & \text{not obtaining} \end{cases}. \tag{2.4}$$

Suppose $C = \{c_i | i \in N\}$ is the CID space set, where N is the natural number set. $C_m(t)$ denotes the CID set that is established for the on-going m-th service at time t. It is obvious that $C_m(t) \subseteq C(t)$.

Then, the process of SID resolution mapping can be expressed as follows,

$$\begin{bmatrix} C_1(t) \\ \vdots \\ C_m(t) \\ \vdots \\ C_M(t) \end{bmatrix} \triangleq \Phi \begin{bmatrix} S_1(t) \\ \vdots \\ S_i(t) \\ \vdots \\ S_I(t) \end{bmatrix}, \tag{2.5}$$

where I denotes the number of the nodes that are obtaining the service in the network,M represents the number of SIDs in the obtaining state, $\Phi(\cdot)$ achieves the transformation from the SID space to the CID space, and the inverse mapping $\Phi^{-1}(\cdot)$ achieves the transformation from the CID space to the corresponding SID space.

The design of the *SID-RM* solves the problem in the traditional Internet in which all the applications are tightly bound with specific network addresses and transport protocols. It is able to make a service independent from a specific network connection. Based on this design, network services are flexibly mapped to the specific CID. Then, the transport protocols and specific service nodes can be shielded, which provides an efficient service-oriented delivery process.

2.3.3 CID Resolution Mapping

CID-RM is used to generate the corresponding relationship between the source nodes and destination nodes, i.e., providing a network connection for an actual content transmission. *CID-RM* achieves the mapping from the CID space to AID space, which chooses the communication connections for network services. *CID-RM* is defined as:

$$\begin{bmatrix} Y_1(t) \\ \vdots \\ Y_i(t) \\ \vdots \\ Y_I(t) \end{bmatrix} \triangleq \Psi \begin{bmatrix} C_1(t) \\ \vdots \\ C_m(t) \\ \vdots \\ C_M(t) \end{bmatrix}. \tag{2.6}$$

where $\Psi(\cdot)$ represents the mapping function, which completes the transformation from CID to corresponding AID pairs during the service acquisition procedure. The inverse mapping function $\Psi^{-1}(\cdot)$ is used to map the corresponding AID pairs back to one connection CID during the process of acquiring network service. I denotes the number of nodes that are obtaining service; M is the total number of SIDs that are being obtained in the network; $Y_i(t)$ is a set of AID relation pairs when node i acquires network services at the time t, which can be expressed as follows:

$$
\begin{aligned}
Y_i(t) &= \sum_{n=1}^{M} Y_i^n d_i^n(t). \\
&= \sum_{n=1}^{M} \sum_{i,k,l} < x_i^{(j)}, x_k^{(l)} >_n d_i^n(t)
\end{aligned}
\tag{2.7}
$$

Here, Y_i^n is a set of AID relation pairs used by node i to acquire the service s_n. $< x_i^{(j)}, x_k^{(l)} >_n$ denotes the existing connection channels between the AID $x_i^{(j)}$ of node i and the AID $x_k^{(l)}$ of node k when node i is acquiring service s_n. It is worth noting that $< x_i^{(j)}, x_k^{(i)} >_n$ may contain multiple sub-channels using different transport protocols.

CID-RM is a key design to connect the upper-layer services and lower-layer network resources. In the traditional Internet, the upper-layer services are all bound with the lower-layer network resource. This results in the problems of connection flexibility, application mobility and communication security, and so on. In the SINET, *CID-RM* is introduced to complete the mapping between connections and services, which has changed the process of traditional end-to-end connection control and is able to solve the aforementioned problems.

With the above three mappings, the network data stream generated for service $s_n (s_n \in S)$ will be delivered through corresponding nodes and links. The inverse mapping processes will be executed to determine which user application receives the service data when the data stream reaches the destination node. According to the preset optimal strategies, the mapping in each level is able to optimize and adjust the network behaviors dynamically based on the network status. To this end, the network will eventually establish appropriate connections to provide services for users, which greatly improves the network performance, such as the availability, security, reliability, controllability and manageability of the Internet. In a word, the different mapping functions $\Omega(\cdot)$,$\Phi(\cdot)$ and $\Psi(\cdot)$ and their inverse mappings build a flexible control and management system for SINET.

2.4 Basic Operations

In SINET, all the network services are provided by three kinds of flexible mappings. In the following, we will illustrate the operations flow of SINET in detail, which is divided into seven basic procedures.

2.4.1 Node Access

As for a new Internet architecture, the intercommunication between the heterogeneous networks is an important metric of the network scalability. To this end, ACN should support various kinds of network terminal nodes. Due to the different types of networks, these nodes may have different AIDs with different forms and lengths. To achieve the uniform access of various nodes with various types, a *unified AID access control* is introduced in SINET for the access process. With this mechanism, any node that requests to access the ACN needs to pass the node access control process. Only for the trusted nodes will the data communications be allowed. If the node passes the authentication, the ASR will be in charge of the mapping from AID to RID and then provides the available resource for the following data routing and forwarding in CON.

2.4.2 Service Registration

In the SINET, network services are managed uniformly according to the *SID allocation*. Every service provider must *identify* its network services and *register* them into the SID Management System (SMS). Then, these services will be looked up and retrieved by users. During the registration, providers need to collect and maintain the resource information of their own services as much as possible, such as the service identifier, service description, service type, resource demand, resource data and resource location. With the knowledge of the information, the provider registers them into the SMS. After that, the SMS will disseminate the registration information over the overall network by using the information exchange protocol among different SMSs for the ease of the retrieval service.

2.4.3 Service Resolution

Generally speaking, the network node is not able to process the user descriptions of the network service demands. Therefore, these verbal descriptions have to be translated into machine language for the ease of processing. This translation process is called the *service resolution*. In the SINET, the service resolution transforms the *keywords* and *abstract* of verbal descriptions into the corresponding services stored in the SMS. Then, the SMS sends back the essential service information, such as the SID and service description, to user nodes according to the service registration and other strategies. Because the SMS may store multiple services, which are matched with the user's service demands, user nodes may receive multiple resolution results. On this occasion, the final service needs to be manually chosen by the user or automatically selected by the SMS.

Even though the service resolution is very important, it is not indispensable. This service resolution can be skipped in the following three situations:

- the application program in user node has been registered at the SMS;
- the information of the demanded network service is already known;
- the user node has cached the service information.

2.4.4 Connection Establishment

After the service resolution, the user has already got the SID of the demanded network service. Then, the user needs to establish the network connections to obtain the service. In the SINET, the user node first sends the service information to a Connection Identifier Management System (CMS) such as the SID. The CMS will generate the *corresponding CID* based on the mapping rules. Then, the CMS will transmit the AID of the service provider and the connection information, such as the transport protocol and congestion control, to the user, according to the preset strategies and current network state. After receiving the information from the CMS, the user node will send the connection request to the corresponding service provider according to the generated CID. When the service provider receives the request, it will complete the mapping from the CID to AID according to its network service and strategies such as the verification of the CID. Finally, a transmission channel of network data based on the acquired CID between user nodes and service nodes will be built.

2.4.5 Data Forwarding

During the acquisition of the network service, the mapping between the AID and RID is also necessary for the packets to pass through the CON. The packets are first routed to the ASR, which is at the edge of the ACN. The ASR will *map* the *AID* to the *RID* according to the service type, quality of service (QoS) and so on. The newly generated RID can be identified and routed by the devices of the CON. Then, the packets are routed in the CON to another ASR at the edge of the ACN. This ASR will map the RID of packets back into the AID. Eventually, the packets are routed and switched to the destination node. It is worth noting that the mapping between the AID and RID has four types: one to one, one to many, many to one and many to many. The four mapping types are determined by the service type, QoS and so on, providing support for the diversified routing.

2.4.6 Node Mobility

During the acquisition of the network service, the service may be interrupted because of the mobility of the user node. To prevent the service interruption, the node needs to complete the following mobile procedures. If the node does not move out of the ACN, the corresponding ASR, CON and correspondent node need not perform any operations. The nodes in the ACN communicate by the means of the flat routing method. If the node moves between different ACNs, the node will be connected to a new ASR. The newly connected ASR will generate a new AID for the node. Then, the ASR will register the mapping relationship at the AID mapping server, and the ASR will cooperate with the ASR of the correspondent node to optimize the subsequent packet transmission path.

2.4.7 Service Migration

Service migration, also called service movement, is a critical metric of *service universality* in the SINET. During the acquisition of service, the service node usually stops providing the service because of data movement, accidental failure and so on. After the user node detects the service interruption, it will adjust the mapping between the CID and AID to select another service node to obtain the service. Therefore, the network connection in the upper layer will remain the same. In this way, the influence of service migration on the upper layer application is avoided, and the service migration is therefore efficiently supported. Moreover, service migration also includes the situations that one of the two nodes in a communication link is changed to a third node or a third node is invited in the network service. For the above two situations, the CID of the network connection built for this service remains unchanged. Only the mapping relationship between the CID and AID needs to be changed.

2.5 Conclusion

This chapter introduces the initiation and fundamentals of the SINET. We first describe the foundational reference model of the SINET. Then, three kinds of resolution mappings are elaborated comprising the SID-RM, CID-RM and AID-RM. Based on the fundamental theory, we further introduce the basic operations of the SINET in terms of node access, service registration, service resolution, connection establishment, data forwarding, node mobility and service migration. All these elements constitute the operational foundations of the SINET. In the following chapters, we will further introduce the principle and technologies of the SINET.

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http://www.springer.com/978-3-662-49141-6

Smart Collaborative Identifier Network
A Promising Design for Future Internet
Zhang, H.; Su, W.; Quan, W.
2016, XXXI, 318 p. 187 illus., 21 illus. in color.,
Hardcover
ISBN: 978-3-662-49141-6